CASE

Educating the Next Generation of Accelerator Physicists and Engineers

Presented at

DOE ONP Accelerator R&D Review
December 12-14, 2011

Derek I. Lowenstein
Collider-Accelerator Department

BROOKHAVEN NATIONAL LABORATORY

CASE Center for Accelerator Science and Education

Office of Science U.S. DEPARTMENT OF ENERGY

The problem we are helping to solve

Only a handful of universities offer any formal training in accelerator science & technology

Accelerator science is a recognized discipline

Accelerators are essential tools for discovery science

Universities can and should have a significant accelerator research role, along with the laboratories

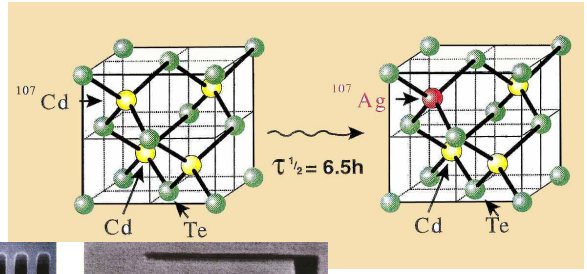
- R&D on higher gradient and higher current machines for nuclear and particle physics are such examples

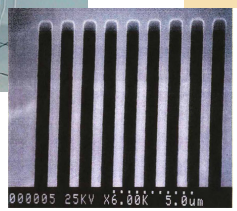
DOE spends almost 1 B$ yearly on major accelerator facilities

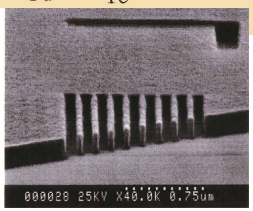
> 26,000 accelerators in medicine, industry & national security constitute a multi-billion dollar/yr industry

> 55,000 peer-reviewed papers having accelerator as a keyword are available on the Web

Motivations: Why does the Nation care? Why should students care?

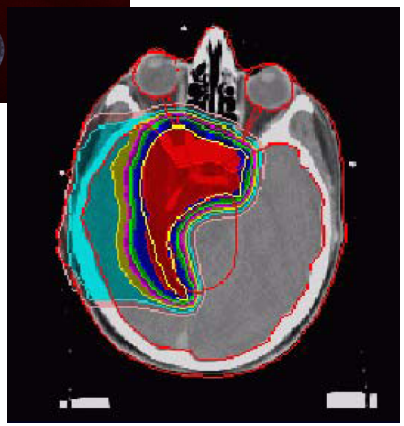




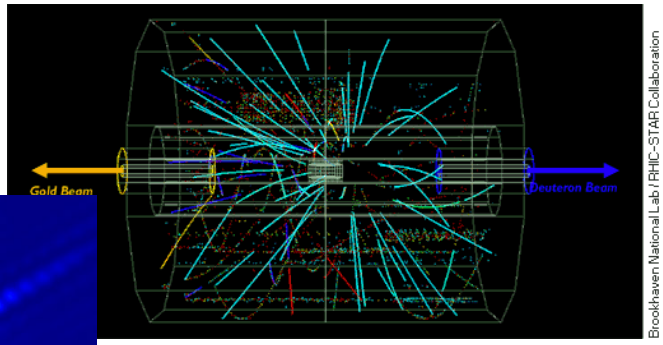


Materials

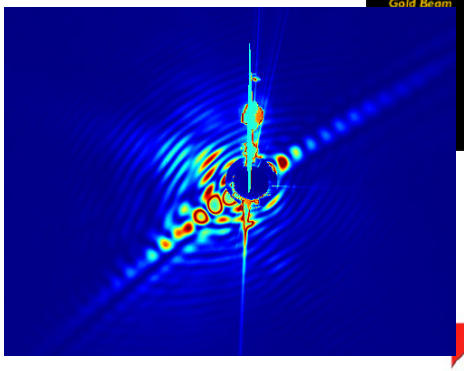
Medicine



Basic Research



Brookhaven National Lab / RHIC-STAR Collaboration

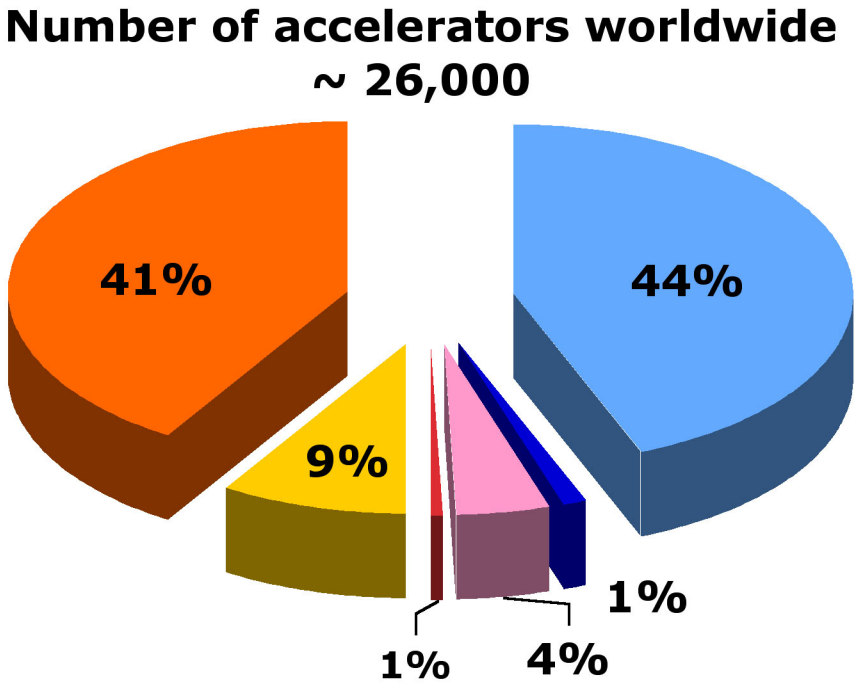


Exciting products…
exciting opportunities

BROOKHAVEN NATIONAL LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

Accelerators are big business



Annual growth is several percent

Sales >3.5 B$/yr

Value of treated good > 50 B$/yr **

There are plentiful jobs at the end of the pipeline for students.

See: http://www.symmetrymagazine.org/cms/?pid=1000802

Sources: W. Maciszewski & W. Scharf, L. Rivkin, * EPP2010, ** R. Hamm

University impediments

Structure:

- Accelerator science is inherently cross-disciplinary
- Experimental accelerator science requires expensive tools

Prejudices:

- Physics departments, “accelerator science is just technology”
- EE departments prefer nano-technology & computing science

Practicalities:

- It is difficult to enroll enough students for university approval
  - Even Cornell, UCLA, & Stanford can only offer core courses
- ***Accelerator R&D at universities is insufficient to support strong faculty lines***

Accelerator-based science needs several more such universities to assure an adequate, well trained professional workforce

Universities with research accelerators

- Emphasize innovation in accelerator science
- Promote undergraduate awareness
  - MSU - 50 UGs annually; Cornell - 60 UGs annually
- Offer exciting opportunities to engineering students
- Encourage student experimentalists to learn about accelerators
- Are a vanishing breed

Universities with strong graduate programs in accelerator physics provide a large student attendance at USPAS to augment their education

- Only Maryland, Cornell, MSU, UCLA, & Stanford have strong faculty lines (>2 professors)

The Stony Brook University / BNL connection provides an ideal educational environment. The close proximity to BNL and the BSA connection provides for a superb combination of both university and national laboratory environment.

The development of CASE capitalizes on resources at both institutions

BNL has a panoply of state of the art accelerators engaged in a broad spectrum of sciences, with many outstanding scientists already affiliated with and teaching at SBU; many of the SBU faculty in various fields already use the existing accelerator based facilities at BNL for their own research;

SBU has a recently retired research accelerator – the Tandem Van de Graaff (TvDG) – which Tom Hemmick has brought back to life and renovated the old control room into a modern Physics Teaching Laboratory (PTL) that serves graduate, undergraduate students as well as K-12 teachers and students.

SBU has significant laboratory space for R&D activities, such as a laser laboratory.

SBU and BNL have the intellectual firepower to make CASE world leading

SBU and BNL have had a previous long term unofficial relationship in training accelerator physicists, e.g. Chao, Ruth, Wei, Weng, Calaga etc.

BNL ACCELERATORS

Nuclear and High Energy Physics

Relativistic Heavy Ion Collider (250 GeV) (2 rings)
AGS 30 GeV proton synchrotron
Booster synchrotron (5 GeV/c)
200 MeV proton linac
750 KeV RFQ linac
15 MeV Tandem Van de Graaff (2)
3 GeV/c muon storage ring
300 KeV/amu EBIS RFQ
2 MeV / amu linac
70 MeV electron linac (Accelerator Test Facility)

Chemistry

10 MeV electron linac
2 MeV Van de Graaff
17.5 MeV cyclotron
19 MeV cyclotron
35 MeV cyclotron

Basic Energy Sciences (NSLS)

2.5 GeV electron storage ring (x-ray)
750 MeV electron storage ring (UV)
750 MeV electron Booster synchrotron
80 MeV electron linac
200 MeV electron linac
230 MeV electron linac (DUV-FEL)
3 GeV NSLSII (under construction)

Biology

Scanning Transmission Electron Microscopes (3)

PROGRESS TO DATE

1. Seed funding provided by SBU and BNL
2. Thomas Hemmick (SBU) and Vladimir Litvinenko (BNL) are co- Directors.
3. Ilan Ben-Zvi is the Deputy Director for Research
4. Derek Lowenstein, "Executive Director", works with SBU management to develop the CASE program; promote an SBU accelerator physics and engineering degree program, increase SBU departments and BNL departments involvement, establish undergraduate summer intern program in accelerator physics and engineering at BNL, US Particle Accelerator School (USPAS) linkage, increase graduate thesis mentoring at BNL.
5. SBU faculty commitment, both physics and engineering, have committed to granting degrees in accelerator science. Brookhaven Professors created (Ben-Zvi, Litvinenko)
6. CASE FY2012 academic courses established

- Established MOU with John Adams Institute for Accelerator Science (JAI) at the University of Oxford including sharing accelerator web-courses. Graduate curriculum committee approved such courses assuming that one CASE professor will be the local host responsible for quality of the course and checking homework.

- Mei Bai: Introduction to Accelerator Physics
- Sergey Belomestnykh: Superconducting RF

7. **SBU is planning to hire new physics faculty in accelerator science. Joint appointments with BNL are being considered.**

8. **SBU / CASE hosted the Summer 2011 US Particle Accelerator School (USPAS).**

9. **SBU Tandem is being used for student laboratory courses.**

10. **Physics Department linac has been removed, resulting in a large new area available as a laser development laboratory.**

11. **<u>CASE Grants</u>**

DE-FG02-08ER41547 DOE HEP "Study of electron transport and amplification in diamond", $0.524M, 7/15/2008 through 7/14/2012, Ilan Ben-Zvi

DE-SC0002496 DOE HEP "R&D on very-high-current superconducting proton linac", $1.235M, 9/15/2009 through 9/14/2012, Ilan Ben-Zvi

DE-SC0005713, DOE BES "Photocathodes for high repetition rate light sources", $1.021M, 1/1/2011 through 12/31/2011, Ilan Ben-Zvi

DE-SC0005713, DOE BES "Photocathodes for high repetition rate light sources", $1.021M, 1/1/2011 through 12/31/2011, Ilan Ben-Zvi

DE-FOA-0000411, DOE HP, NP, BES “2011 Particle Accelerator Conference”, $20K, 10/1/10 through 9/30/11, Vladimir Litvinenko

DE-FOA-0000339, DEO NP, “Experimental Demonstration of Coherent Electron Cooling at RHIC”, $5.888M, 10/27/10 – 9/30/15, BNL grant with $320K subcontract to support CASE students, FY11 funds $1,488M received, Vladimir Litvinenko

12. **10 SBU undergraduate students were enrolled in the REU and SULI programs at BNL, Summer 2010. Supported by CASE, SBU and BNL.**

13. **3 SBU postdocs and 11 graduate thesis students presently being mentored by Collider-Accelerator Department staff. ~15 pre-CASE BNL mentored students granted PhD. Several of whom are leaders in the field. All supported by BNL. 2 students received a PhD in 2011.**

14. **5 graduate students attended the June 2010 USPAS at MIT. Supported by CASE and BNL.**

THE CENTER FOR ACCELERATOR SCIENCE AND EDUCATION


NATHAN COOK


ELIZABETH GANGONE


PhD granted

LEE HAMMONS


ELLIOTT JOHNSON

STEVE WEBB


TIANMU XIN


PUNEET JAIN


OMER RAHMAN


XUE LIANG


MIGUEL RUIZ OSES


JIN DAI


PRACHI CHITNIS


ANDREY ELIZAROV


KEREN LI

CASE Building

SBU Physics Students at CASE

Andrey Elizarov, Vladimir Litvinenko
Collective effects and beam dynamics in eRHIC with coherent electron cooler

Lee Hammonds, Vladimir Litvinenko
Higher-Order Mode Damping in the ERL
Defended on November 28, 2011

Elliott Johnson, Ilan Ben-Zvi
Higher Order Mode damping in a superconducting accelerating cavity

Tianmu Xin, Ilan Ben-Zvi
High quantum efficiency photocathode, diamond amplified photocathode

Omer Rahman, Ilan Ben-Zvi
Polarized Electron funneling photocathode gun

Elizabeth Gangone, Triveni Rao,
Diamond amplified photocathode capsule

Nathan Cook, Axel Drees,
Ion beam based therapy

Stephen Webb, Vladimir Litvinenko
Theoretical Considerations of Coherent Electron Cooling
Defended on May 12, 2011

SBU Engineering School Students at CASE

Mengjia Gaowei (Material Science Eng. Dept., Prof. Michael Dudley), John Smedley;
High quantum efficiency photocathode, diamond amplifiers

Liang Xue (Material Science Eng. Dept., Prof. Michael Dudley), Ilan Ben Zvi;
High quantum efficiency photocathode, multi-alkaline photocathodes

Prachi Chitnis (Computer Eng. Dept., Prof. Thomas Robertazzi), Kevin Brown;
Machine Protection Improvements for RHIC and eRHIC

SBU Physics and Astronomy Post Docs

Puneet Jain, Ilan Ben-Zvi
High-current superconducting accelerating cavity

Miguel Ruiz Oses, Ilan Ben-Zvi
High quantum efficiency photocathodes

Jin Dai, Ilan Ben-Zvi
High quantum efficiency photocathodes

SBU Physics and Astronomy Staff

Erik Muller, Research Scientist, Ilan Ben-Zvi
High quantum efficiency photocathode, diamond amplifiers

Significant publications

Erdong Wang, Ilan Ben-Zvi, Xiangyun Chang, Qiong Wu, Triveni Rao, John Smedley, Jorg Kewisch, and Tianmu Xin, Systematic study of hydrogenation in a diamond amplifier, Physical Review Special Topics - Accelerators And Beams 14, 061302 (2011)

T. Vecchione, I. Ben-Zvi, D. H. Dowell, J. Feng, T. Rao, J. Smedley, W. Wan, and H. A. Padmore, A Low Emittance and High Efficiency Visible Light Photocathode for High Brightness Accelerator-Based X-ray Light Sources, Appl. Phys. Lett. 99, 034103 (2011)

H. Hahn, I. Ben-Zvi, R. Calaga, L. Hammons, E. C. Johnson, J. Kewisch, V. N. Litvinenko, and Wencan Xu, Higher-order-mode absorbers for energy recovery linac cryomodules at Brookhaven National Laboratory, Phys. Rev. ST Accel. Beams 13, 121002 (2010).

D. A. Dimitrov, R. Busby, J. R. Cary, I. Ben-Zvi, T. Rao, J. Smedley, X. Chang, J. W. Keister, Q. Wu, and E. Muller, Multiscale three-dimensional simulations of charge gain and transport in diamond, JOURNAL OF APPLIED PHYSICS 108, 073712 (2010)

X. Chang, Q. Wu, I. Ben-Zvi, A. Burril, J. Kewisch, T. Rao, J. Smedley, E. Wang, E. M. Muller, R. Busby, and D. A. Dimitrov, Electron Beam Emission from a Diamond-Amplified Cathodes, Physical Review Letters 105, 164801 (2010)

HOM absorbers for ERL cryomodules at BNL, H. Hahn, I. Ben-Zvi, R. Calaga, L. Hammons, V. N. Litvinenko, W. Xu, Physics Review Special Topics Accelerator and Beams 13, 121002 (2010), 14 pages, http://prst-ab.aps.org/abstract/PRSTAB/v13/i12/e121002

Physics of FEL in an infinite electron beam, G. Wang, V. N. Litvinenko and S. D. Webb, Submitted to Physics Review Special Topics – Accelerators and Beams, September 2010

Three-dimensional model of small signal free-electron lasers, Stephen Webb, Gang Wang and Vladimir Litvinenko, Physics Review Special Topics – Accelerators and Beams, 14, 051003 (2011), 8 pages, http://prst-ab.aps.org/abstract/PRSTAB/v14/i5/e051003

On Free-Electron Laser Growing Modes and their Bandwidth, Stephen Webb, Gang Wang and Vladimir Litvinenko, Submitted to Physics Review Letters, Ma[illegible]

Evolution of Electron Beam Phase Space Distribution in a High-gain FEL, Stephen Davis Webb, Vladimir N. Litvinenko, Proceeding of 31st International Free Electron Conference, Liverpool, UK, 23-28 August, 2009, pp. 208-210

A 3-Dimensional Theory of Free Electron Lasers, Stephen Davis Webb, Vladimir N. Litvinenko, Gang Wang, In Proc. of 32nd International Free Electron Laser Conference, Malmo, Sweden, August 23-27, 2010

Dispersion Relations for 1D High-Gain FELs, Stephen Davis Webb, Vladimir N. Litvinenko, In Proc. of 32nd International Free Electron Laser Conference, Malmo, Sweden, August 23-27, 2010

Vladimir N. Litvinenko, Johan Bengtsson, Ilan Ben-Zvi, Alexei V. Fedotov, Yue Hao, Dmitry Kayran, George Mahler, Wuzheng Meng, Thomas Roser, Brian Sheehy, Roberto Than, Joseph Tuozzolo, Gang Wang, Stephen Davis Webb, Vitaly Yakimenko, Andrew Hutton, Geoffrey Arthur Krafft, Matt Poelker, Robert Rimmer, George I. Bell, David Leslie Bruhwiler, Brian T. Schwartz, Proof-of-Principle Experiment for FEL-based Coherent Electron Cooling, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, March 25-April 1, 2011

G. Wang, V. Litvinenko, S.D. Webb, Amplification of Current Density Modulation in a FEL with an Infinite Electron beam, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, March 25-April 1, 2011

S.D. Webb, V. Litvinenko, G. Wang, Effects of e-beam Parameters on Coherent Electron Cooling, 2011 Particle Accelerator Conference, New York, NY, USA, March 25-April 1, 2011

CASE INITIATIVES

CASE contributions to C-AD accelerator R&D

To incorporate state-of-the-art science/engineering and interdisciplinary university R&D with that of a national laboratory.

1. Laser acceleration of protons and ions aimed at radiation therapy.
   - Assets: Laser acceleration program at the ATF and SBU laboratory space.
   - Progress to date: Protons accelerated to 1.5 MeV in a distance of 1mm.

2. Energy Recovery Linac R&D, aimed at electron – ion colliders and X-ray FELs.
   - Assets: The high current ERL facility at BNL.

3. Advanced beam cooling techniques, aimed at collider luminosity increase and polarization of protons (possibly He3) beams.
   - Assets: The nuclear physics program at BNL.

4. Design and construction of a next generation proton/carbon synchrotron to treat cancer (CRADA funding)
   - Assets: CRADA with Best Medical International Corporation. NASA Space Radiation Laboratory excellent dosimetry etc. test bed.
   - Phase II CRADA about to start. Construction of some first articles.

Dose Distribution of Radiation Considering Biological Effects

When the ratios of peak to plateau (a/b) are compared while considering biological effect, the carbon beam has the largest value.

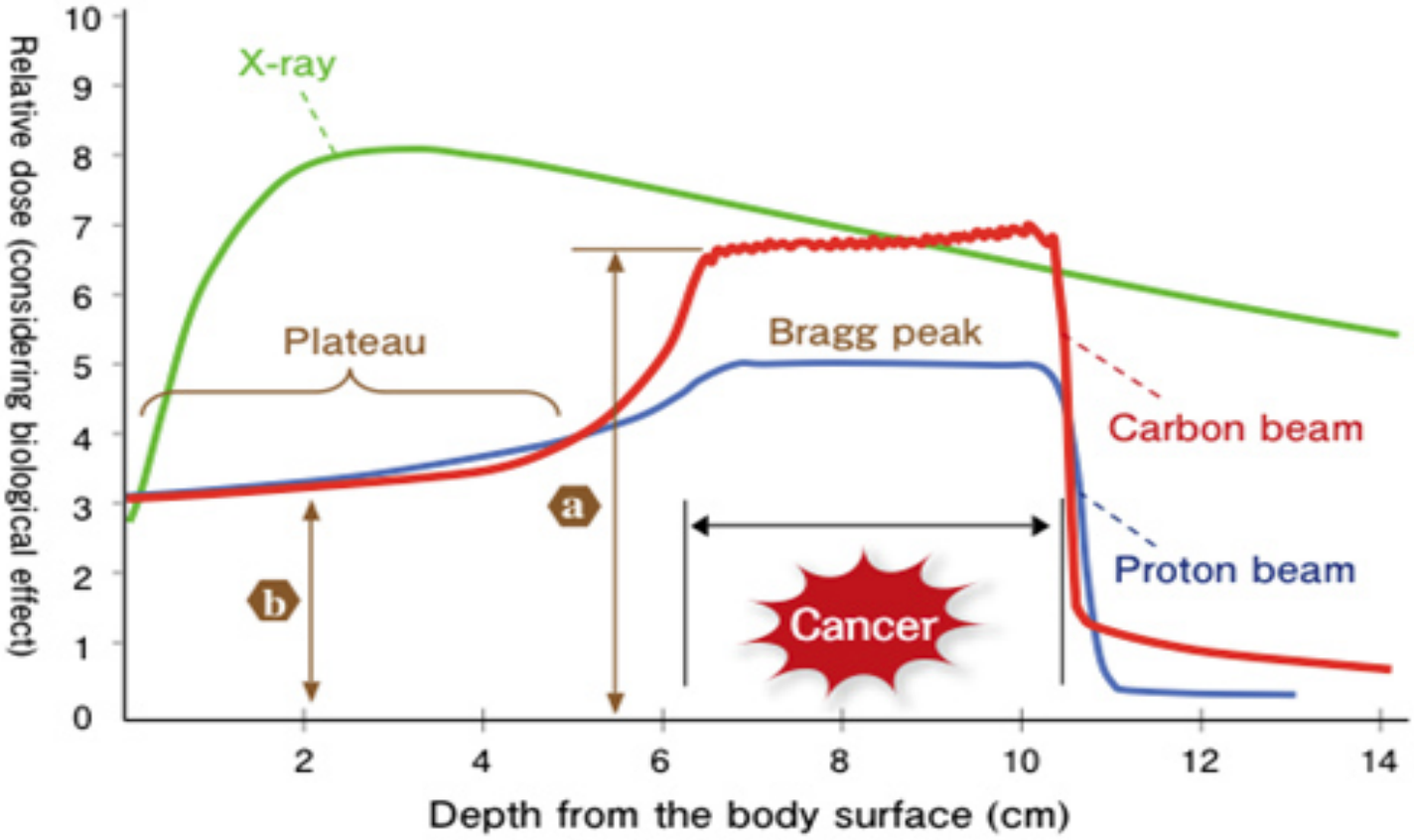
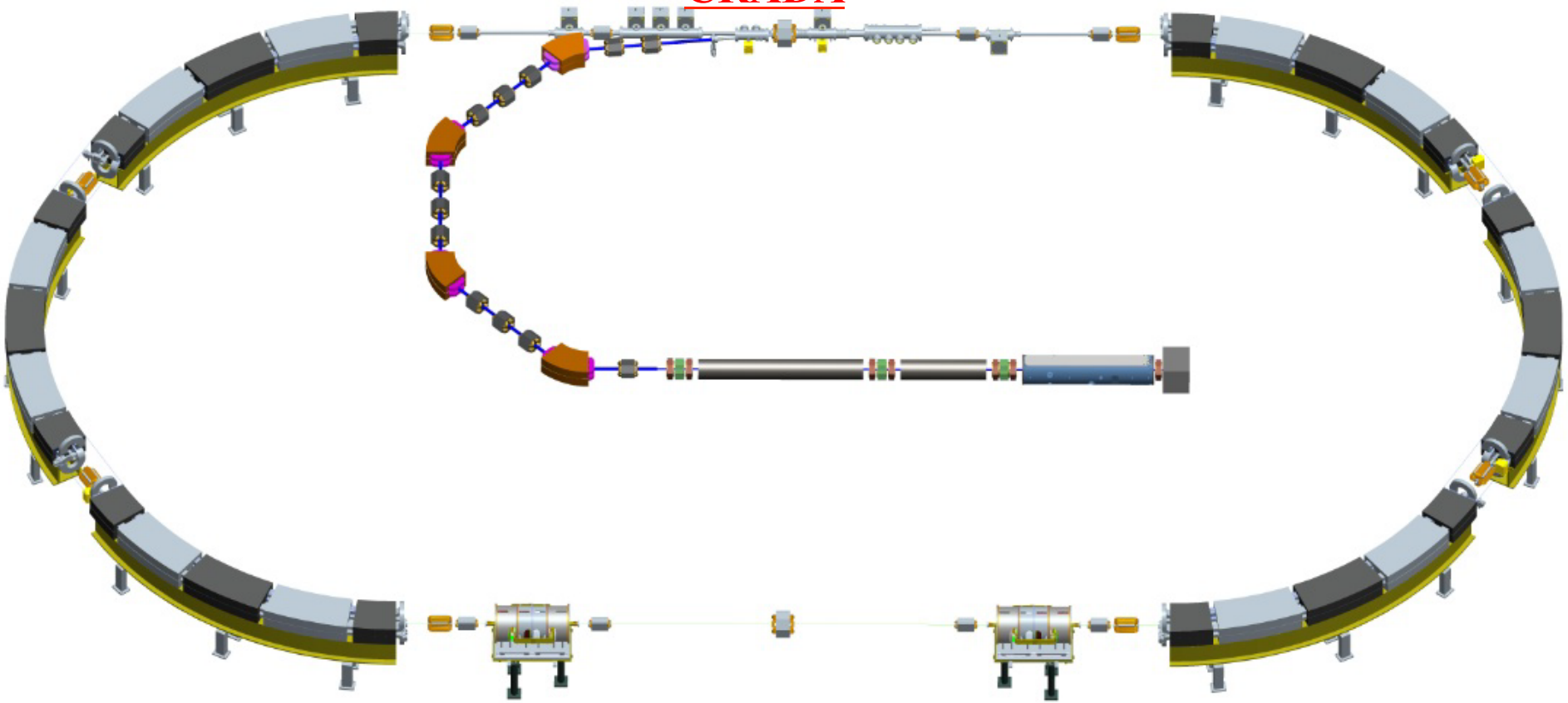


Illustration courtesy of National Institute of Radiological Sciences (NIRS)

The dose distributions clearly illustrate the advantages associated with particle therapy by the elimination of the distal dose. It is worth pointing out that X-rays can often achieve excellent conformity using IMRT techniques or implanting very low-energy gamma ray sources; but the unmistakable advantage of particle therapy is associated with precise control of particle penetration depth.

ion Rapid Cycling Medical Synchrotron not including transport and patient treatment areas.

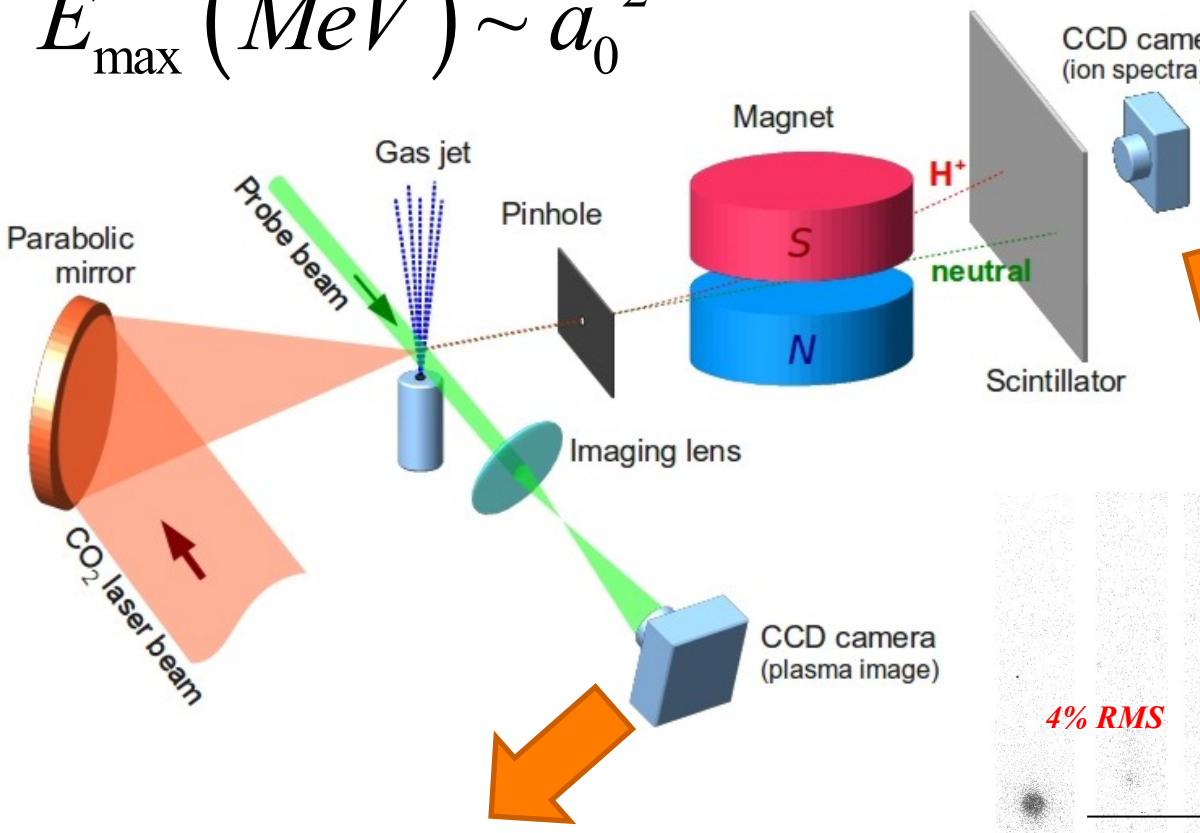
Best Medical International/BNL CRADA

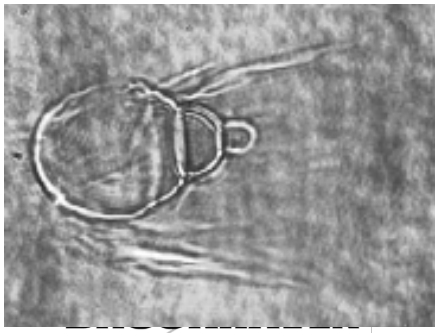


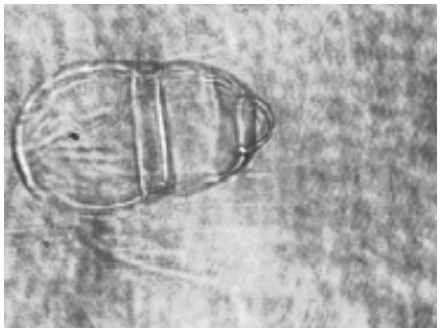
BEYOND THE NEXT GENERATION THERAPY ACCELERATOR

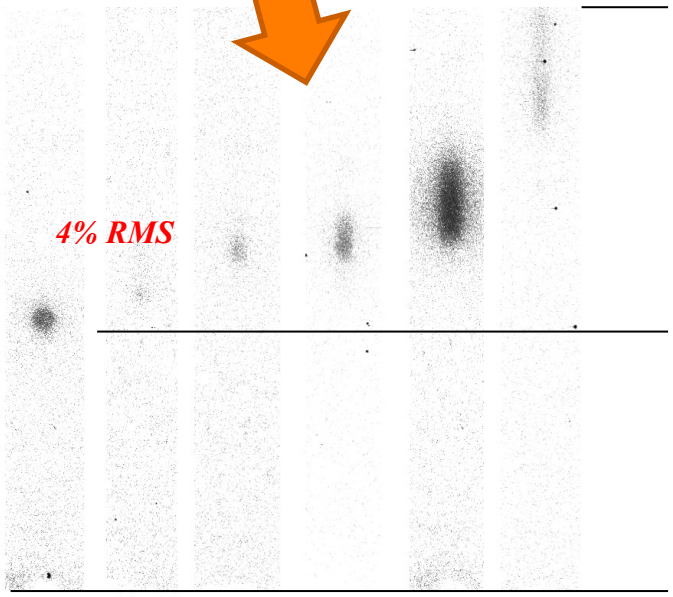
Monoenergetic ion beam by Radiation Pressure Acceleration from H_2 gas jet

$$E_{\max}\left(MeV\right) \sim a_0^{\,2}$$









In summary:

The CASE Mission:

Pursue cutting edge accelerator R&D,

Train next generation accelerator physicists and engineers **-graduate & post doctoral**

Attract undergraduate students to the graduate program **through introductory courses, laboratory work & summer internships at BNL**

Promote interdisciplinary research **amongst SBU and BNL departments**

We encourage both SBU faculty & student involvement.

Joint SBU and BNL effort to nurture & grow existing efforts in accelerator science

BNL's accelerator facilities provide unique opportunities for cutting-edge graduate & undergraduate accelerator research